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Fielhauer et al.

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(45) **Date of Patent: Apr. 17, 2007**

(54) **METHOD OF REMOTELY ESTIMATING A REST OR BEST LOCK FREQUENCY OF A LOCAL STATION RECEIVER USING TELEMETRY**

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(51) **Int. Cl.**
H04Q 7/20 (2006.01)
H04B 7/19 (2006.01)
H01S 13/08 (2006.01)

(52) **U.S. Cl.** **455/427**; 455/431; 455/13.1; 342/104

(58) **Field of Classification Search** 455/26.1, 455/502, 427, 429, 431, 13.1; 342/173, 174, 342/104
See application file for complete search history.

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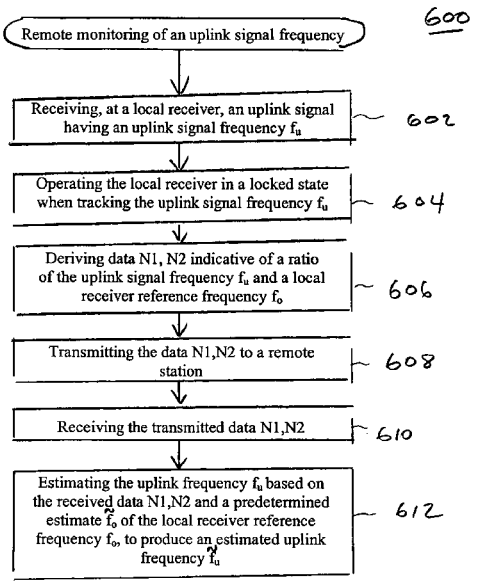
(57) **ABSTRACT**

A system includes a remote station and a local station having a receiver. The receiver operates in an unlocked state corresponding to its best lock frequency (BLF). The local station derives data indicative of a ratio of the BLF to a reference frequency of the receiver, and telemeters the data to the remote station. The remote station estimates the BLF based on (i) the telemetered data, and (ii) a predetermined estimate of the reference frequency.

14 Claims, 7 Drawing Sheets



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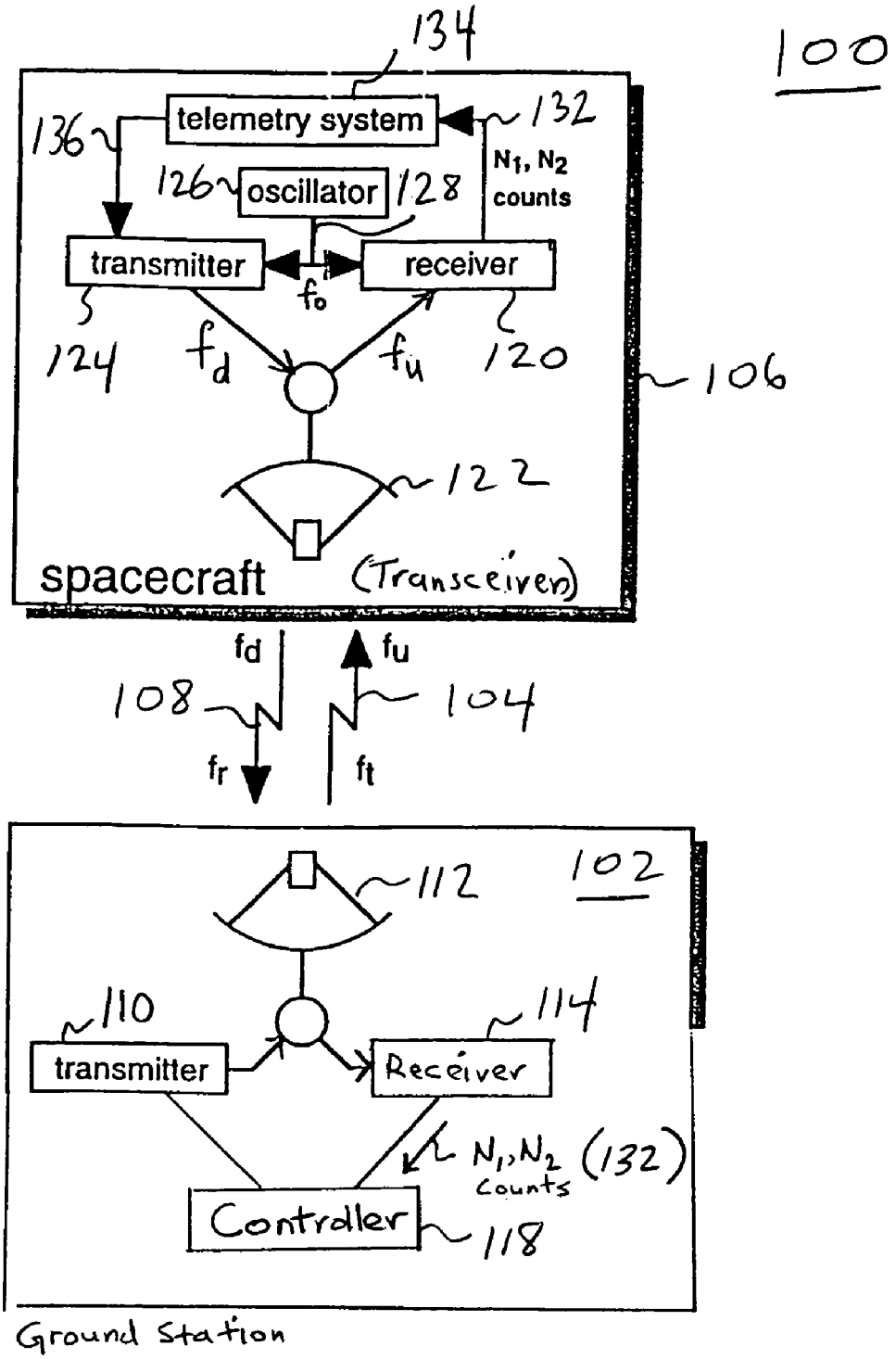

100
134
telemetry system
132
136
N_1, N_2 counts
126
oscillator
128
transmitter
receiver
f_o
124
f_d
f_u
120
106
122
spacecraft
(Transceiver)
fd
fu
108
104
fr
ft
112
102
110
114
transmitter
Receiver
N_1,N_2 (132) Counts
Controller
118
Ground Station

FIG. 1

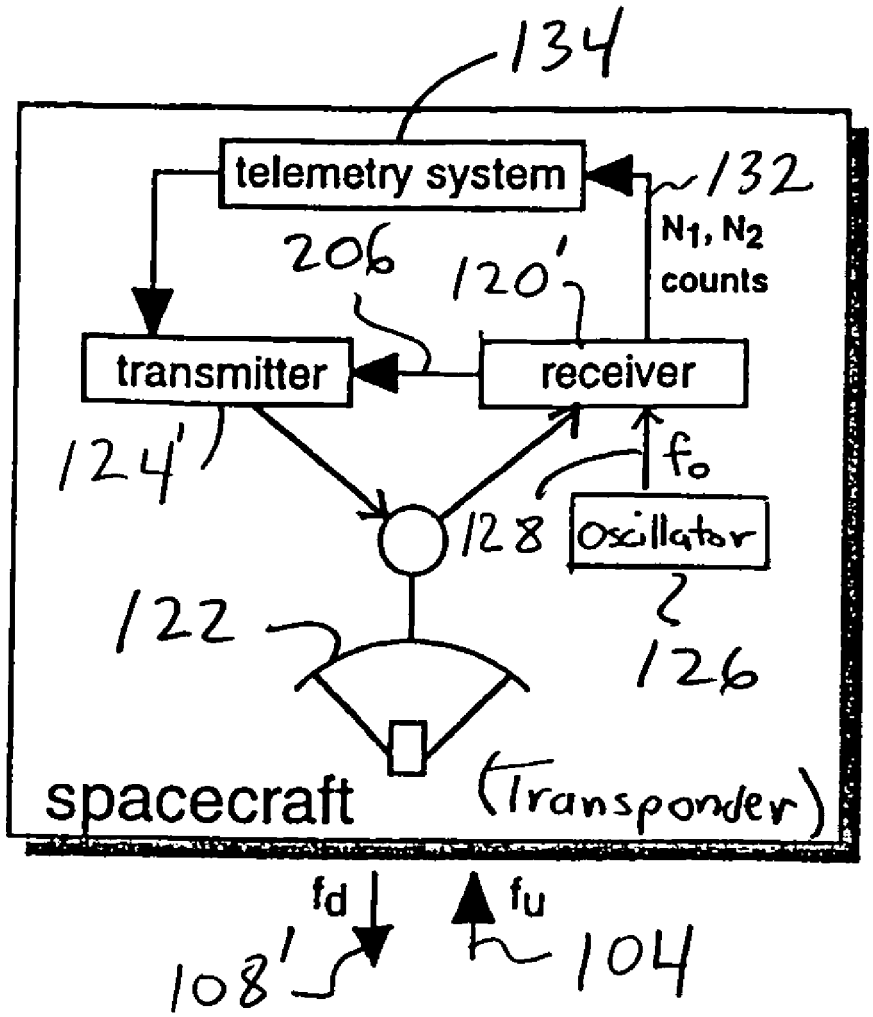

134
202
telemetry system
132
N1, N2
counts
206
120'
transmitter
receiver
124'
fo
128
Oscillator
122
126
spacecraft
(Transponder)
fd
fu
108'
104

FIG. 2

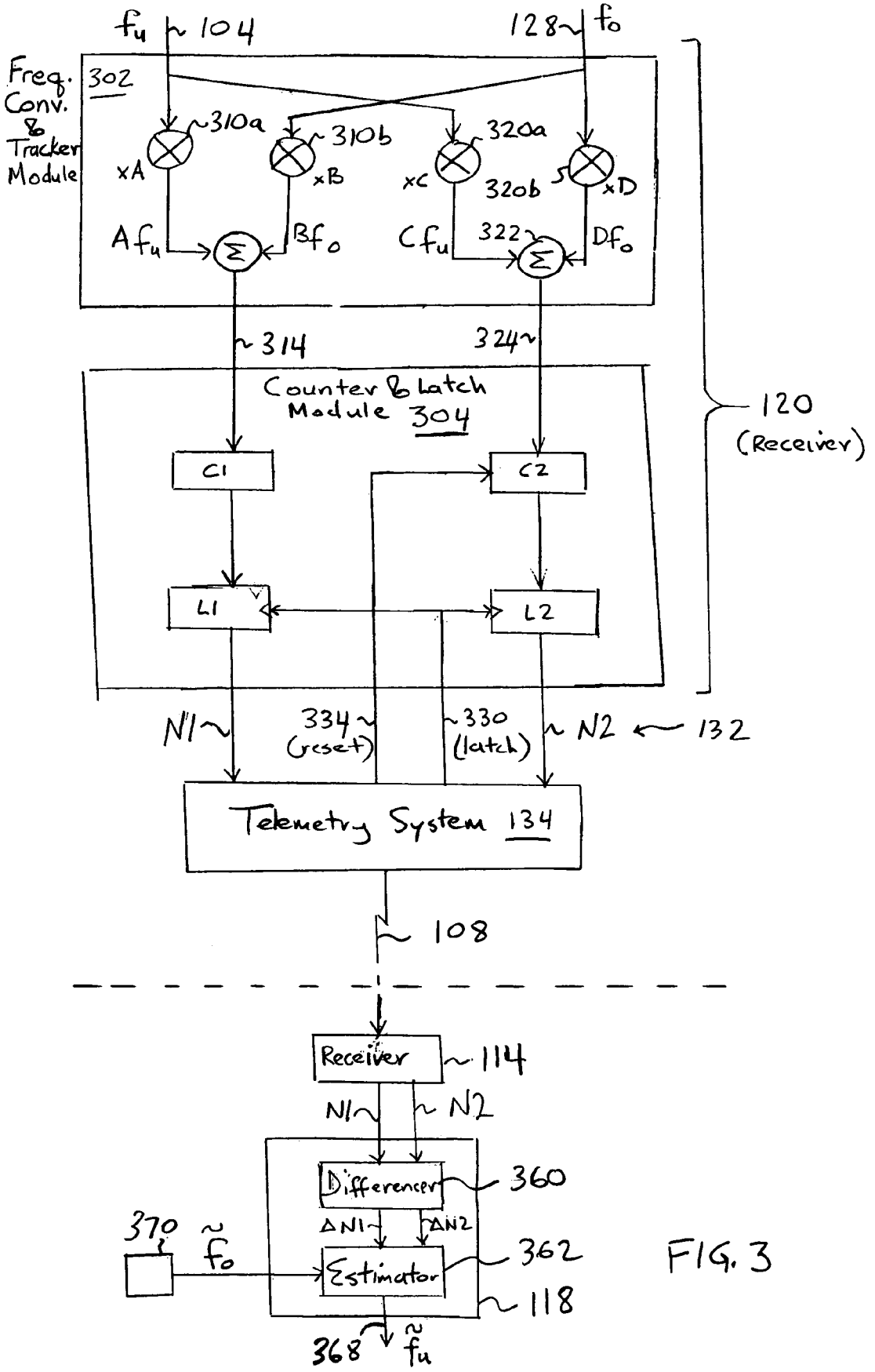
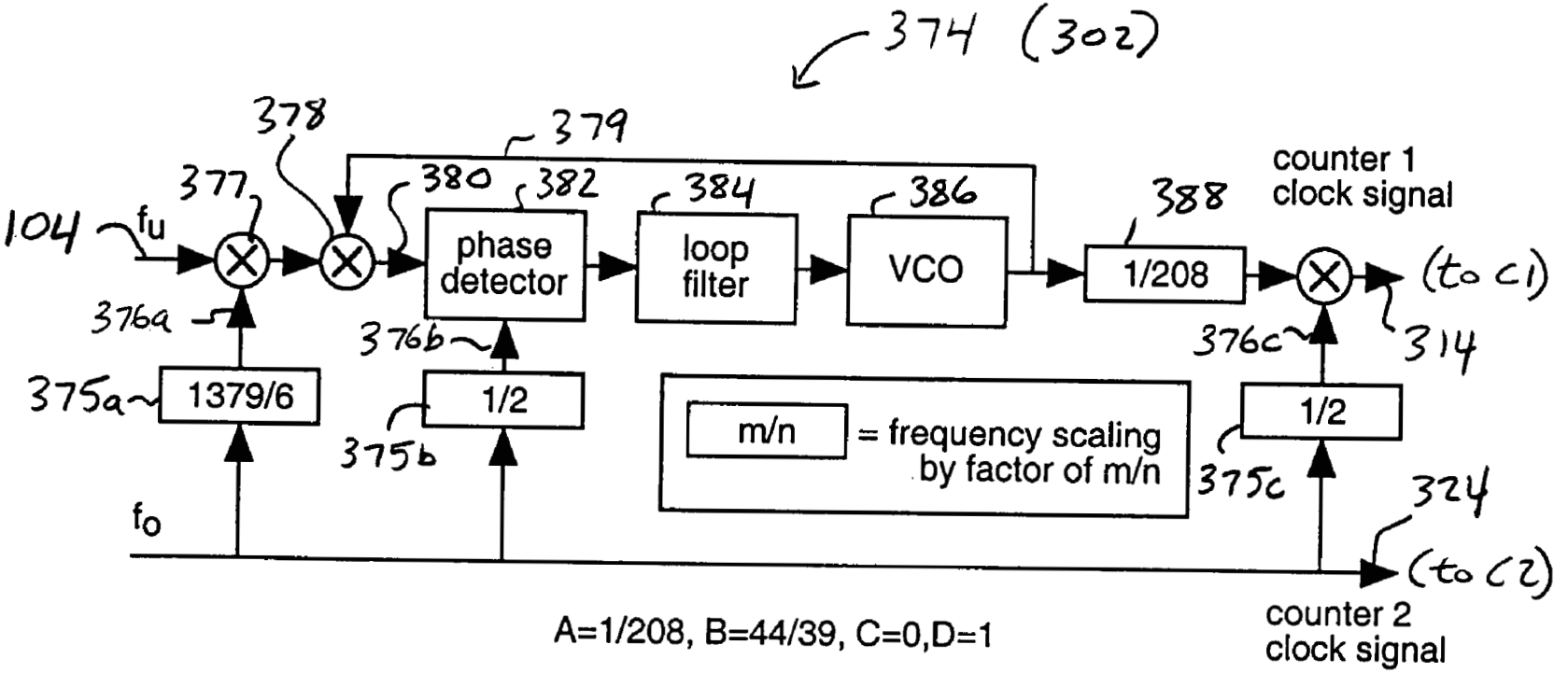

f_u 104
128 f_o
Freq. Conv. & Tracker Module 302
310a
310b
320a
320b
xA
xB
xC
xD
Af_u
Bf_o
Cf_u
Df_o
322
314
324
Counter & Latch Module 304
C1
C2
L1
L2
120 (Receiver)
N1
334 (reset)
330 (latch)
N2
132
Telemetry System 134
108
Receiver 114
N1
N2
Differencer 360
ΔN1
ΔN2
370
f_o
Estimator 362
118
368
$\tilde{f}_u$

FIG. 3


374 (302)
378
379
377
380
382
384
386
388
counter 1 clock signal
104
fu
phase detector
loop filter
VCO
1/208
(to c1)
376a
376b
376c
314
375a
1379/6
1/2
375b
m/n = frequency scaling by factor of m/n
1/2
375c
324
fo
(to c2)
A=1/208, B=44/39, C=0,D=1
counter 2 clock signal

302

FIG. 3A

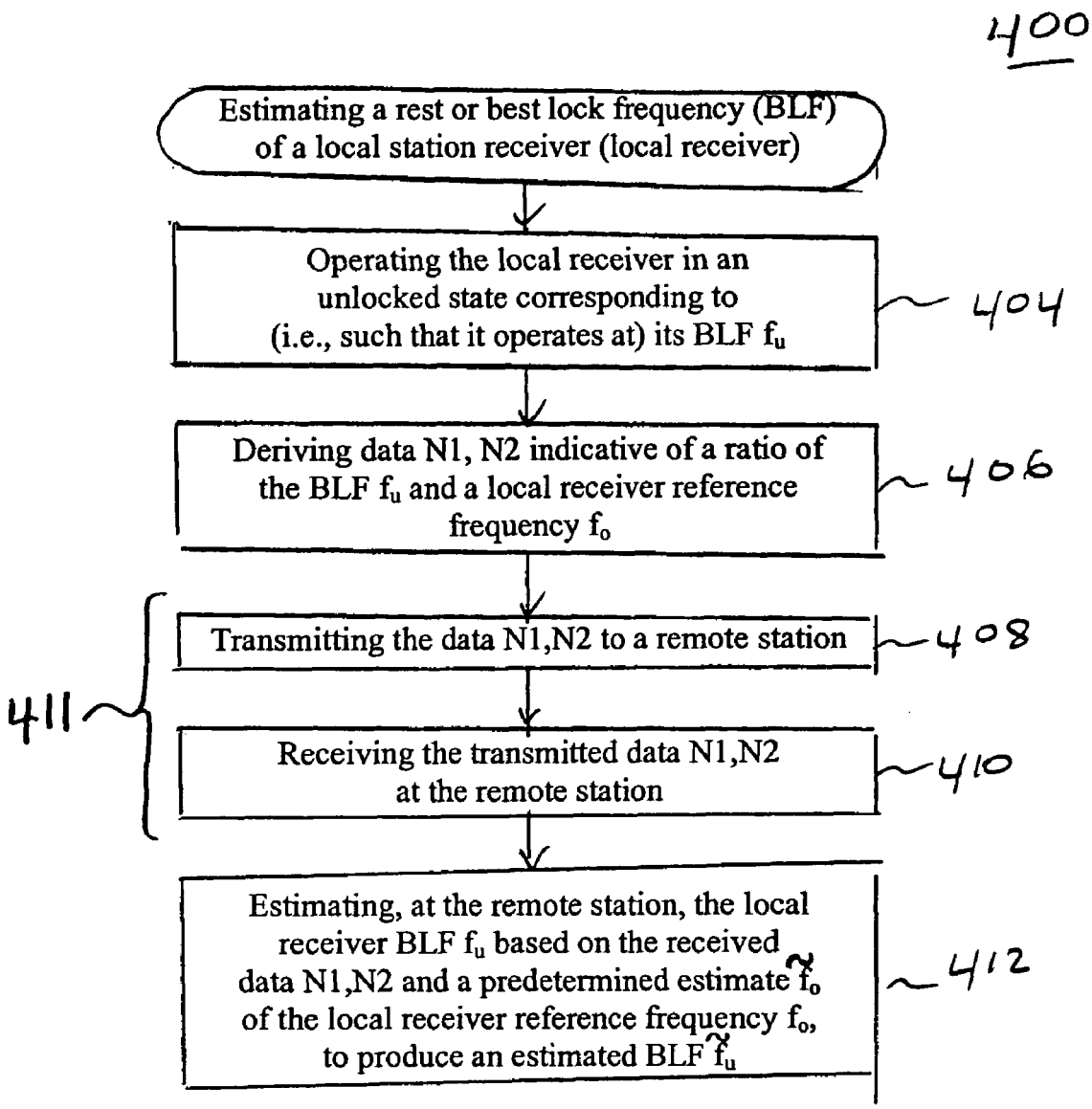

400
Estimating a rest or best lock frequency (BLF) of a local station receiver (local receiver)
Operating the local receiver in an unlocked state corresponding to (i.e., such that it operates at) its BLF f_u
404
Deriving data N1, N2 indicative of a ratio of the BLF f_u and a local receiver reference frequency f_o
406
411
Transmitting the data N1,N2 to a remote station
408
Receiving the transmitted data N1,N2 at the remote station
410
Estimating, at the remote station, the local receiver BLF f_u based on the received data N1,N2 and a predetermined estimate $\tilde{f}_o$ of the local receiver reference frequency f_o, to produce an estimated BLF $\tilde{f}_u$
412

FIG. 4

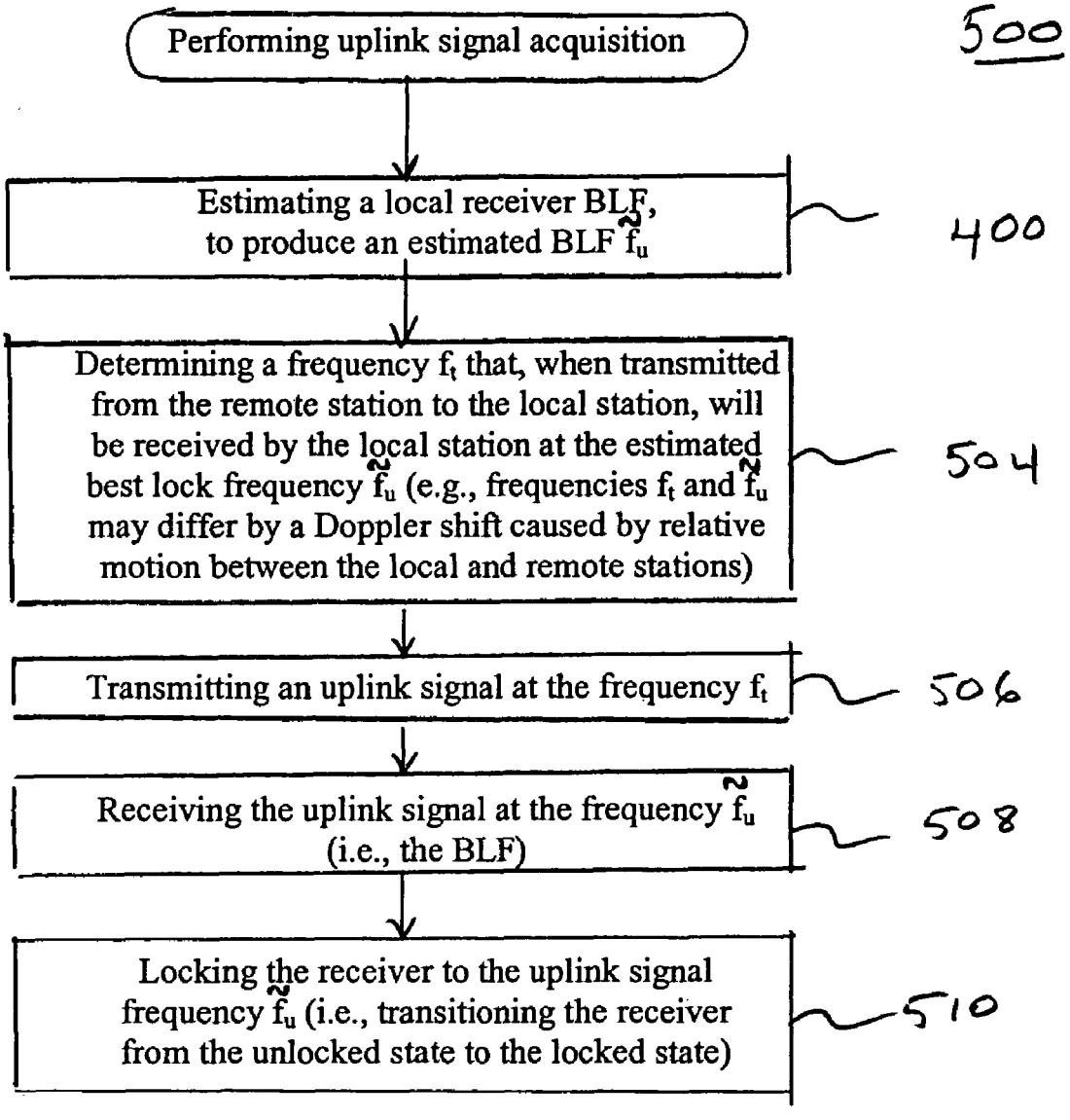

Performing uplink signal acquisition
500
Estimating a local receiver BLF, to produce an estimated BLF $\tilde{f}_u$
400
Determining a frequency f_t that, when transmitted from the remote station to the local station, will be received by the local station at the estimated best lock frequency $\tilde{f}_u$ (e.g., frequencies f_t and $\tilde{f}_u$ may differ by a Doppler shift caused by relative motion between the local and remote stations)
504
Transmitting an uplink signal at the frequency f_t
506
Receiving the uplink signal at the frequency $\tilde{f}_u$ (i.e., the BLF)
508
Locking the receiver to the uplink signal frequency $\tilde{f}_u$ (i.e., transitioning the receiver from the unlocked state to the locked state)
510

FIG. 5

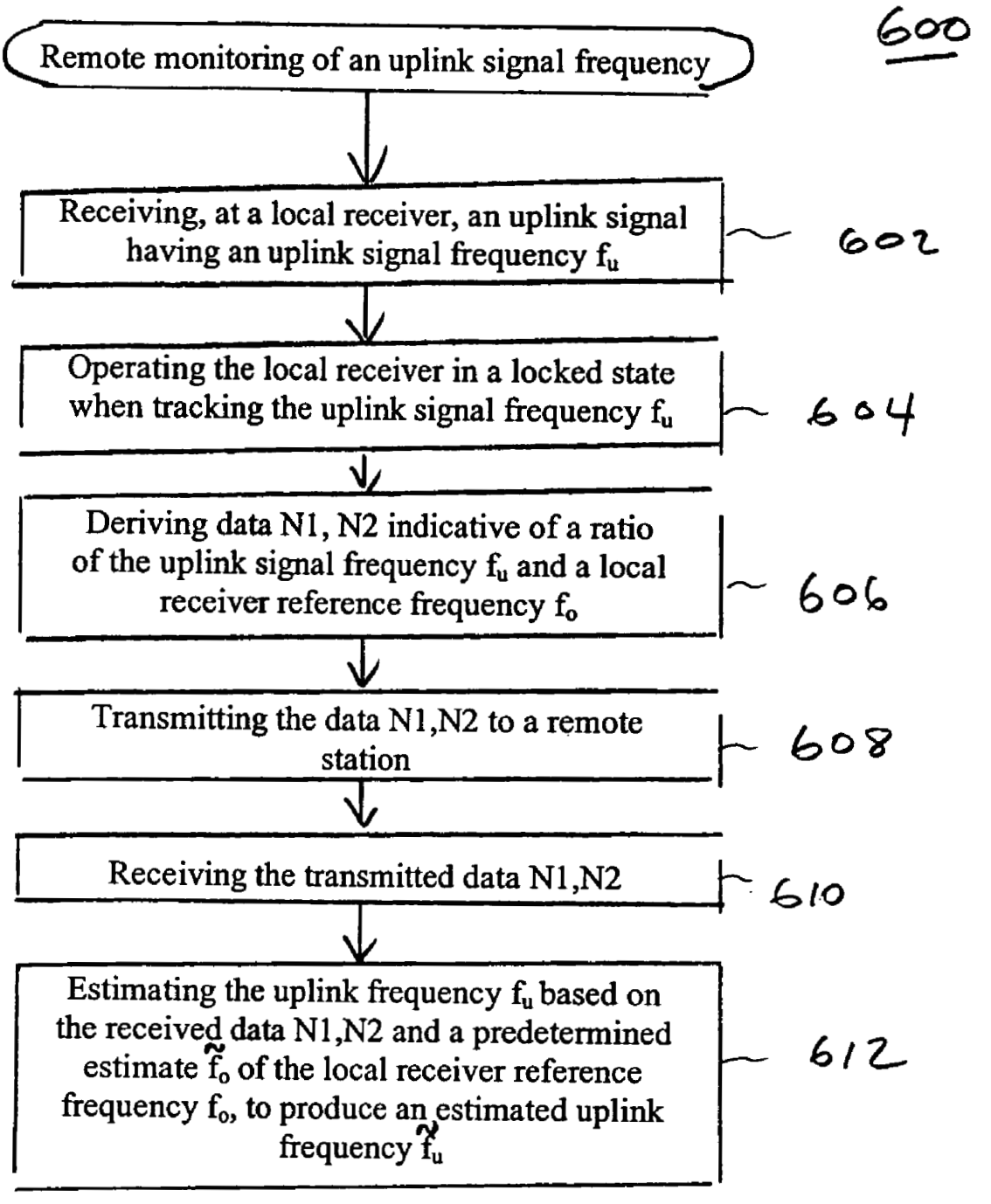

600
Remote monitoring of an uplink signal frequency
Receiving, at a local receiver, an uplink signal having an uplink signal frequency f_u
602
Operating the local receiver in a locked state when tracking the uplink signal frequency f_u
604
Deriving data N1, N2 indicative of a ratio of the uplink signal frequency f_u and a local receiver reference frequency f_o
606
Transmitting the data N1,N2 to a remote station
608
Receiving the transmitted data N1,N2
610
Estimating the uplink frequency f_u based on the received data N1,N2 and a predetermined estimate $\tilde{f}_o$ of the local receiver reference frequency f_o, to produce an estimated uplink frequency $\hat{f}_u$
612

FIG. 6

METHOD OF REMOTELY ESTIMATING A REST OR BEST LOCK FREQUENCY OF A LOCAL STATION RECEIVER USING TELEMETRY

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit U.S. Provisional Application No. 60/434,259, filed on Dec. 18, 2002, the contents of which are incorporated herein by reference in their entirety.

STATEMENT OF GOVERNMENTAL INTEREST

This invention was made with Government support under Contract No. NAS5-97271 awarded by NASA. The Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to systems including a control station and a remote receiver, and more specifically, to such a system wherein the control station remotely monitors an operating frequency of the receiver using telemetry.

2. Discussion of the Related Art

In a typical satellite system, a ground station transmits an uplink signal to a satellite and the satellite transmits a downlink signal to the ground station. The satellite includes a receiver configured to phase and/or frequency track the uplink signal. That is, in the presence of the uplink signal, the receiver locks onto and tracks the uplink signal frequency (referred to as the uplink frequency) and/or phase. However, in the absence of the uplink signal, the receiver is unlocked, i.e., free-running, and thus settles to a rest frequency, also referred to as best lock frequency (BLF). The BLF corresponds to the uplink frequency that, if present, would cause the receiver to transition from the unlocked state to the locked state in a minimum amount of time and with a minimum amount of frequency pull-in. The BLF can be considered a natural frequency of the receiver.

The receiver may have a relatively narrow uplink frequency pull-in range typically encompassing the BLF. However, the BLF is typically uncertain, i.e., not precisely known. Thus, in a known technique for uplink frequency acquisition, the ground station sweeps the uplink frequency over a relatively wide frequency range anticipated to include the uncertain BLF. When the swept uplink frequency moves near to the BLF and is within the frequency pull-in range, the receiver captures or locks onto and tracks the uplink frequency, and is said to have acquired the uplink signal.

Causes of BLF uncertainty include, for example, receiver temperature variations and component (e.g., oscillator) aging, or other physical effects. The larger the BLF uncertainty, the larger the uplink frequency sweep range, and disadvantageously, the larger the uplink signal acquisition time. It is desirable to minimize or eliminate the BLF uncertainty, and correspondingly narrow the uplink signal sweep range, so as to minimize the uplink signal acquisition time. Therefore, it would be advantageous to be able to accurately determine the BLF at the ground station. In other words, it would be advantageous to be able to monitor at the ground station the BLF of the spacecraft receiver.

After the uplink frequency is acquired, the ground station performs two-way Doppler tracking of the uplink and downlink signals (i.e., frequencies). The accuracy of the Doppler tracking depends on an accuracy with which the ground station can determine the uplink frequency as received at the satellite. Thus, there is a need to be able to accurately determine at the ground station the uplink frequency as received at the satellite. In other words, there is a need to monitor at the ground station the uplink frequency at the satellite.

These and other embodiments of the present invention will become apparent from the ensuing description.

SUMMARY OF THE INVENTION

An embodiment of the present invention includes a method of remotely monitoring a BLF of a local receiver.

Another embodiment of the present invention includes a method of remotely monitoring an uplink frequency received at a local station.

A system in which the embodiments may operate includes a remote station, such as a ground station, and a local station, such as a spacecraft. The local station includes a receiver having first and second digital counters. The first counter is clocked at a relatively low rate related to a down-converted and scaled frequency that is input to the receiver, which may represent either (i) the BLF of the receiver in the absence of an uplink frequency, or (ii) an uplink frequency input to the receiver when the uplink signal is present. The second counter is clocked at a high rate related to a frequency of a local reference frequency of the receiver.

The receiver includes latch logic configured to simultaneously latch first and second counter output values of the first and second counters, respectively, responsive to a trigger signal in the receiver. The latch logic operates repeatedly to generate successive pairs of first and second counter values. The successive pairs of counter values are indicative of a ratio of either (i) the uplink frequency, or (ii) the BLF, to the reference frequency.

The local station telemeters the successive pairs of counter values to the remote station. The remote station determines either (i) the uplink frequency, or (ii) the BLF, based on the successive pairs of telemetered counter values and a predetermined estimate of the reference frequency available at the remote station.

In the absence of the uplink signal, the present invention enables a user at the remote station (e.g., ground station) to remotely determine the BLF of the receiver. The BLF represents the frequency that, if injected into the input of the receiver, will place the least stress on an uplink signal tracking system in the receiver and permit the tracking system to quickly establish receiver lock using an efficient frequency sweep strategy. This advantageously improves the use of costly ground station time.

In the presence of the uplink signal, the present invention enables the user at the ground station to remotely determine the uplink frequency at the receiver, to maintain the uplink frequency at a desired frequency in the presence of Doppler shifts, and roughly estimate the Doppler velocity without the use of a ground-based Doppler measurement.

In another application, the ground station combines the telemetered successive counter values with a telemetered phase-locked loop static phase error (produced by the receiver tracking system) in order to monitor variations in the BLF over time. This allows the ground station to maintain the uplink frequency near the BLF and to ascertain what uplink frequency will quickly lock-up the receiver if the uplink signal link, between the ground station and spacecraft, is broken and must be re-established.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages will become more readily apparent from the detailed description of the invention accompanied by the following drawings, in which:

FIG. **1** is a block diagram of an example system in which the present invention can operate.

FIG. **2** is an example transponder configuration of a spacecraft depicted in FIG. **1**.

FIG. **3** is a block diagram of example portions of the spacecraft and a ground station depicted in FIG. **1**, relevant to the present invention.

FIG. **3**A is a block diagram of an example arrangement of a Frequency Converter and Tracker module of FIG. **3**.

FIG. **4** is a flow chart of an example method of remotely estimating a rest or best lock frequency of a local station receiver, performed in the system of FIG. **1**.

FIG. **5** is a flow chart of an example method of performing, in the system of FIG. **1**, an uplink signal acquisition.

FIG. **6** is a flowchart of an example method of remotely monitoring an uplink signal frequency provided to a local station.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Definition

The term "receiver frequency" used herein denotes a frequency f_u at which a receiver operates, and can mean either (i) an uplink frequency when an uplink frequency is present and the receiver is in the locked state, or alternatively, (ii) a rest frequency or BLF of the receiver when the receiver is unlocked, e.g., when the uplink frequency is not present.

System

FIG. **1** is a block diagram of an example system **100** in which the present invention can operate. In a first operational arrangement of system **100**, depicted in FIG. **1**, a ground station **102** transmits an uplink signal **104** to a spacecraft **106**, such as a satellite, for example. Spacecraft **106** transmits a downlink signal **108** to ground station **102**. Relative motion between ground station **102** and spacecraft **106** will typically cause Doppler shifts in uplink signal **104** and downlink signal **108**, as would be apparent to one having ordinary skill in the relevant art(s). Thus, uplink signal **104** has a frequency f_t at ground station **102** and a Doppler shifted frequency f_u at spacecraft **106**, while downlink signal **108** has a frequency f_d at spacecraft **106** and a Doppler shifted frequency f_r at ground station **102**. Spacecraft **106** may trace a trajectory relative to ground station **102** such that the uplink signal **104** and downlink signals **108** experience no Doppler shift, i.e., frequency f_t=frequency f_u, and frequency f_d=frequency f_r. In an X-band uplink and X-band downlink system, for example, f_t might be 7.18185 GigaHertz (GHz) and f_d might be 8.4380 GHz, although any combination of radio frequencies might be used.

Ground station **102** includes a transmitter **110** for transmitting uplink signal **108** through an antenna **112**. Ground station **102** also includes a receiver **114** for receiving downlink signal **104** through antenna **112**. A controller **118**, coupled with transmitter **110** and receiver **114**, controls ground station **102**, and performs methods in accordance with the present invention, as will be described below.

Spacecraft **106** includes a receiver **120** for receiving uplink signal **104** through an antenna **122**. A transmitter **124** transmits downlink signal **108** through antenna **122**. Receiver **120** and transmitter **124** together represent a spacecraft transceiver. An oscillator **126** provides a reference signal **128**, having a reference frequency f_o, to both receiver **120** and transmitter **124**. The arrangement of spacecraft **106** depicted in FIG. **1** is referred to as a transceiver configuration. In the transceiver configuration, transmitter **124** derives downlink signal **108** independent of the phase and frequency of uplink signal **104**.

In the presence of uplink signal **104**, receiver **120** operates in a locked state, wherein the receiver tracks uplink frequency f_u. Receiver **120** generates a count signal **132**, including count values N**1** and N**2**, indicative of a ratio of uplink frequency f_u to reference frequency f_o (i.e., f_u/f_o), and provides count signal **132** to a telemetry system **134**. Telemetry system **134** encodes count signal **132** into a telemetry stream **136**. Transmitter **124** transmits telemetry stream **136** to ground station **102** through downlink signal **108**. Receiver **114** of ground station **102** recovers count signal **132** from downlink signal **108** and passes the same to controller **118**. Controller **118** determines, that is, estimates, uplink frequency f_u based on count signal **132**. In this manner, system **100** determines uplink frequency f_u at spacecraft **106**. While FIG. **1** shows the counts **132** to originate within the receiver, they may, in principle be generated within the transmitter or in any other subsystem where the necessary signals are present.

The first operational arrangement of system **100** described above assumes spacecraft receiver **120** operates in the presence of uplink signal **104**. In a second operational arrangement, receiver **120** operates in the absence of uplink signal **104**, that is, uplink signal **104** is not present. In the second arrangement, receiver **120** operates in an unlocked (i.e., free-running) state, and thus settles to a rest or best-lock frequency (BLF).

The BLF corresponds to the uplink signal frequency f_u that, if present, would cause receiver **120** to transition from the unlocked state to the locked state in a minimum amount of time and with a minimum amount of frequency pull-in. For this reason, the term "frequency f_u" as used herein is synonymous with the term "receiver frequency" and denotes either (i) uplink frequency f_u when the uplink signal **104** is present, or alternatively, (ii) the rest frequency or BLF of receiver **120** when the receiver is not locked to the uplink signal, e.g., when the uplink signal is not present. The receiver frequency is the frequency at which receiver **120** operates.

In the second operational arrangement (uplink signal not present), receiver **120** generates count signal **132** indicative of a ratio of the BLF to reference f_o. Spacecraft **106** transmits downlink signal **108** to ground station **102**. Ground station **102** recovers count signal **132** and passes the count signal to controller **118**. Controller **118** determines the BLF based on count signal **132**.

FIG. **2** is an example transponder configuration **202** of spacecraft **106**. In transponder configuration **202**, oscillator **126** provides reference signal **128** to receiver **120'** only. Receiver **120'** produces a reference signal **206** that is phase and/or frequency locked to uplink signal **104**, and provides reference signal **206** to transmitter **124'**. Transmitter **124'** generates downlink signal **108'** such that it is also phase and/or frequency locked to reference signal **206**, and thus uplink signal **104**.

In addition to satellite systems, such as system **100**, the present invention may be implemented a terrestrial system wherein ground station **102** and spacecraft **106** are replaced with a base station and a terrestrial mobile and/or fixed

terminal, respectively. Such a base station may be arranged in either a transceiver configuration or a transponder configuration.

FIG. **3** is a block diagram of example portions of spacecraft **106** and ground station **102**, relevant to both the first operational arrangement (uplink signal present) and the second operational arrangement (uplink signal not present) of present invention described above. As depicted in FIG. **3**, spacecraft receiver **120** includes a Frequency Converter and Tracker module **302** coupled to a Counter and Latch module **304**. Module **302** includes signal processing modules configured to (i) frequency down-convert uplink signal **104**, and (ii) phase and/or frequency-lock to, i.e., track, uplink signal **104**, when the uplink signal is present. In the absence of uplink signal **104**, module **302** operates at the BLF of receiver **120**.

Frequency Converter and Tracker module **302** includes parallel frequency multipliers **310***a* and **310***b* for frequency multiplying uplink/BLF frequency f_u and f_o by values A and B, respectively, to produce frequencies $A \cdot f_u$ and $B \cdot f_o$, respectively. Following parallel multipliers **310**, a combiner **312** combines, e.g., adds or subtracts, the multiplied frequencies from multipliers **310**, to produce a first linear combination signal **314** having a frequency equal to $A \cdot f_u + B \cdot f_o$, where B may be negative. In a similar manner, parallel frequency multipliers **320***a* and **320***b*, and a frequency combiner **322**, operate on reference frequencies f_o and f_u to produce a second linear combination signal **324** having a frequency equal to $C \cdot f_u + D \cdot f_o$, where D may be negative. Values A,B are linearly independent of values C,D. As an example of these parameters, for an uplink frequency f_u, of 7.18185 GHz and a frequency reference f_o, of 30.6 MegaHertz (MHz), appropriate values of the parameters might be A=1/208, B=44/39, C=0, and D=1, resulting in signals **314** and **324** having frequencies of 5048 Hertz (Hz) and 30.6 MHz, respectively.

Telemetry system **134** generates a measurement trigger at a fixed, known time within each downlink telemetry frame. Telemetry system **134** uses the measurement trigger to (i) derive a reset signal **334**, and (ii) enable a subsequent latch signal or pulse **330**, which the telemetry system provides to Counter and Latch module **304**. The measurement trigger may be derived from other sources, including commands telemetered from ground station **102** to spacecraft **106**, fixed or scheduled timers, events local to spacecraft **106**, and so on. The measurement triggers should occur frequently enough or on a known schedule so that there is little or no ambiguity in latched values N**1**, N**2** due to counter roll-over in counters C**1**, C**2**. Measurement triggers that do not occur at fixed, known points within each telemetry frame enable subsequent latch signal **330** but do not provide reset signal **344**. Once a latch in module **304** has been enabled (discussed below), latch signal **330** is asserted at a beginning of a next cycle of count signal **314**.

Counter and Latch module **304** includes signal processing elements configured to produce count values N**1**,N**2**, of count signal **132**, responsive to linear combination signals **314**, **324**, latch signal **330**, and counter reset **334**. Counter reset **334** resets counter C**2** of module **320**. Subsequently, counters C**1**, C**2** count cycles of respective linear combination signals **314**, **324**. Latches L**1**, L**2** of module **320** simultaneously latch respective count values or counts N**1**, N**2** of counters C**1**, C**2** responsive to latch enable **330**, and provide the count values to telemetry system **134**. Telemetry system **134** downlinks count values N**1**, N**2** to receiver **114** of ground station **102**, via downlink signal **108**. In an embodiment, counters C**1**, C**2** and latches L**1**, L**2** are implemented in digital logic, and count values N**1**, N**2** are digital values. Additional embodiments and/or details directed to generating count values N**1**, N**2** on a spacecraft are given in the following U.S. Patents, which are incorporated by reference herein in their entireties: U.S. Pat. Nos. 5,995,039; 5,745,072; and 6,650,279.

Receiver **114** derives count values N**1**, N**2** from downlink signal **108** and provides such values to controller **118** of ground station **102**. Controller **118** produces an estimate **368** ($\hat{f}_u$) of uplink frequency f_u, or alternatively, BLF f_u, based on recovered count values N**1**, N**2** and an predetermined estimate $\hat{f}_o$ of reference frequency f_o. Predetermined estimate $\hat{f}_o$ may be stored, for example, in a memory module **370** accessible by controller **118**.

The above-described operations repeat continuously over time to produce a series of recovered count values N**1**, N**2** and corresponding frequency estimates $\hat{f}_u$ In an embodiment, controller **118** includes a differencer module **360** configured to (i) subtract successive values of N**1** from each other to produce count difference values ΔN**1**, and (ii) subtract successive values of N**2** from each other to produce count difference values ΔN**2**. This subtraction process accounts for the fact that one or both of counters C**1**, C**2** may have "rolled over" (gone from a maximum count to zero) between latched values as a result of a limited number of bits in counters C**1**, C**2**. This process of "unrolling" counters C**1**, C**2** can be performed on the basis of known information about the frequencies of linear combination signals **314** and **324** and a relationship of these signals to the timing of the telemetry frames. After the above-described differencing and unrolling is completed, an estimator **362** determines estimate $\hat{f}_u$ based on count differences ΔN**1**, ΔN**2** and predetermined reference frequency $\hat{f}_o$.

FIG. **3**A is a block diagram of an example arrangement **374** of Frequency Converter and Tracker module **302** of FIG. **3**. Arrangement **374** includes dividers **375***a–c* to divide reference frequency f_o, and thereby produce respective frequency divided reference signals **376***a–c*. Successive frequency down-converters or mixers **377** and **378** frequency down-convert uplink frequency f_u to a signal **380** (frequency f_{dc}), responsive to (i) signal **376***a*, and (ii) a feedback signal **379**. A phase and/or frequency detector **382**, a loop filter **384** and a Voltage Controlled Oscillator (VCO) **386** operate together as a phase and/or frequency tracking loop for tracking signal **380**. VCO generates feedback signal **379**. A divider **388** and subsequent mixer **390** operate on VCO output **379** to produce signal **314**.

When uplink signal **104** is present, the tracking loop tracks signal **380**, i.e., is locked to signal **380**, and thus receiver **120** operates in its locked state. In contrast, when uplink signal **104** is not present, the tracking loop is free-running, and thus receiver **120** operates in its unlocked state. In this condition, the tracking loop settles to a rest frequency, that is, the tracking loop will cause VCO **386** to oscillate at its rest frequency. Given the architecture depicted in FIG. **3**A, the rest frequency of the tracking loop implies, i.e., corresponds to, an uplink frequency f_u referred to herein as the BLF, as would be apparent to one of ordinary skill in the relevant art(s) given the present description.

Method Flow Charts

Methods of remotely monitoring (i.e., determining or estimating) a local receiver frequency that may be performed in system **100**, for example, are now described in connection with FIGS. **4–6**. In the methods, spacecraft **106** is considered a local station and ground station **102** is considered a remote station. Thus, ground station **102** remotely monitors the frequency at which local receiver **120**

operates. That is, ground station **102** remotely monitors receiver frequency f_u (the uplink frequency, or alternatively, the BLF). Each of the methods described below may be performed with both the transceiver (FIG. **1**) and transponder (FIG. **2**) configurations of spacecraft **106**.

Remote Estimation of Local Receiver BLF

FIG. **4** is a flow chart of an example method **400** of remotely monitoring, i.e., estimating, rest or best lock frequency f_u of local station receiver **120** (referred to as the local receiver), performed in the second operational arrangement of system **100**.

In a first step **404**, spacecraft receiver **120** operates in the absence of an uplink signal. Thus, receiver **120** operates in its unlocked state. That is, receiver **120** operates at its rest or BLF f_u.

In a next step **406**, modules **302** and **304** of receiver **120** operate together to derive data, e.g., count values N**1**, N**2**, indicative of a ratio of BLF f_u to reference frequency f_o. Step **406** includes the following further steps:

(i) telemetry system **134** generates counter reset **334** and latch signal **330**;

(ii) Frequency Converter and Tracker module **302** produces linear combination signals **314**, **324** from frequencies f_u, f_o; and

(iii) Counter and Latch module **304** counts cycles of signals **314**, **324** occurring between pulses of counter reset **334** and latch signal **330** (i.e., over an elapsed time period), to produce count values N**1**, N**2** respectively.

Step **406** repeats to produce successive sets of corresponding count values N**1**, N**2**.

In a next step **408**, spacecraft **106** transmits or downlinks data, i.e., count values N**1**, N**2** (e.g., successive sets of count values N**1**,N**2**), to ground station **102**.

In a next step **410**, ground station **102** receives the data transmitted in step **408**. Steps **408** and **410** collectively represent a step **411** of telemetering count values N**1**, N**2** from spacecraft **106** to ground station **102**.

In a next step **412**, ground station receiver **114** recovers count values N**1**, N**2** from signal and provides the same to controller **118**. Controller **118** determines estimate $\hat{f}_u$ of BLF f_u based on recovered count values N**1**, N**2** and predetermined estimate $\hat{f}_o$ of receiver reference frequency f_o. In an embodiment, step **412** includes the following further steps:

(i) differencer module **360** subtracts successive values of N**1** from each other to produce count difference values ΔN**1**;

(ii) differencer module **360** subtracts successive values of N**2**, corresponding to the successive values of N**1**, from each other to produce count difference values ΔN**2**; and

(iii) estimator **362** determines frequency estimate $\hat{f}_u$ based on count differences ΔN**1**, ΔN**2** and predetermined reference frequency $\hat{f}_o$.

Estimator **362** determines frequency estimate $\hat{f}_u$ in accordance with the following expression:

$$\hat{f}_u=\hat{f}_o(B-Dr)/(Cr-A),$$

where r=ΔN**1**/ΔN**2**.

In this manner, both ratio r (i.e., ΔN**1**/ΔN**2**) and the corresponding ratio N**1**/N**2**, are indicative of frequency $\hat{f}_u$.

Uplink Signal Acquisition

FIG. **5** is a flow chart of an example method **500** of performing an uplink signal acquisition, performed in system **100**, for example.

First step **400**, corresponding to method **400**, is described above in connection with FIG. **4**. First step **400** includes estimating BLF f_u of receiver **120**, to produce estimated BLF $\hat{f}_u$.

In a next step **504**, controller **118** determines a frequency f_t that, when transmitted from ground station **102** to spacecraft **106**, will be received at spacecraft **106** at or at least near to estimated BLF $\hat{f}_u$, (e.g., frequencies f_t and f_u may differ by a Doppler shift or offset caused by relative motion between ground station **102** and spacecraft **106**). Exemplary methods related to determining and tracking such a Doppler shift are given in U.S. Pat. Nos. 5,995,039, 5,745,072 and 6,650,279.

In a next step **506**, ground station **102** transmits uplink signal **108** at the frequency f_t.

In a next step **508**, spacecraft **106** receives uplink signal **108** at the Doppler-shifted frequency $\hat{f}_u$ (i.e., at the estimated BLF).

In a next step **510**, receiver **120** captures and locks to the uplink signal frequency $\hat{f}_u$ (i.e., receiver **120** transitions from its unlocked state to its locked state).

Remote Estimation of Uplink Frequency at Local Receiver

FIG. **6** is a flowchart of an example method **600** of remotely monitoring, i.e., estimating, uplink frequency f_u provided to local station receiver **120**, performed in the first operational arrangement of system **100**. Method **600** enables ground station **102** to remotely monitor uplink frequency f_u as received at spacecraft **108**.

In a first step **602**, spacecraft **106** receives and acquires uplink signal **108**.

In a next step **604**, receiver **120** operates in its locked state when tracking uplink signal frequency f_u.

In the next step **606**, modules **302** and **304** of receiver **120** operate together to produce successive values of count values N**1**, N**2** indicative of the ratio of uplink signal frequency f_u to local receiver reference frequency f_o.

In a next step **608**, spacecraft **106** transmits the successive values of count values N**1**, N**2** to ground station **102**.

In the next step **610**, count values N**1**, N**2** are received at ground station **102**.

In a next step **612**, ground station **102**, that is, controller **118**, estimates uplink frequency f_u based on recovered count values N**1**, N**2** and predetermined estimate $\hat{f}_o$, to produce estimated uplink frequency $\hat{f}_u$.

It will be understood that various modifications may be made to the embodiments disclosed herein. Therefore, the above description should not be construed as limiting the scope of the invention, but merely as exemplifications of the preferred embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. In a system including a local station and a remote station, the local station including a receiver capable of operating in an unlocked state when not tracking an uplink signal, the unlocked state corresponding to a best lock frequency (BLF) of the receiver, a method of remotely monitoring the BLF, comprising:

(a) in the local station, operating the receiver in the unlocked state corresponding to the BLF; concurrently

(b) in the local station, deriving data indicative of a ratio of the BLF to a reference frequency of the receiver;

(c) telemetering the data indicative of the ratio from the local station to the remote station; and

(d) in the remote station, estimating the BLF based on (i) the telemetered data indicative of the ratio, and (ii) a predetermined estimate of the reference frequency, to produce an estimated BLF wherein step (b) comprises: producing a first linear combination frequency as a first linear combination of the BLF and the reference frequency; producing a second linear combination fre-

quency as a second linear combination of the BLF and the reference frequency; repeatedly counting cycles of the first linear combination frequency to produce successive first count values; and repeatedly counting cycles of the second linear combination frequency to produce successive second count values corresponding to the successive first count values, wherein the successive first and second count values represent the data indicative of the ratio.

2. The method of claim **1**, further comprising:

(e) transmitting, from the remote station to the local station, an uplink signal having an uplink frequency that will be received at the local station at the estimated BLF; and

(f) in the local station, locking the receiver to the uplink frequency.

3. The method of claim **2**, wherein the uplink frequency transmitted in step (e) is either:

(i) the estimated BLF, or

(ii) offset from the estimated BLF by an amount substantially equal to a Doppler shift arising from relative motion between the remote station and the local station.

4. The method of claim **1**, wherein step (a) includes operating the receiver in the absence of an uplink signal.

5. The method of claim **1**, wherein the BLF is the uplink frequency that, if received at the receiver, would cause the receiver to transition from the unlocked state to a locked state in a minimum amount of time.

6. The method of claim **1**, wherein:

step (c) comprises telemetering the successive first and second count values from the local station to the ground station; and

step (d) comprises estimating the BLF based on (i) the telemetered successive first and second count values, and (ii) the predetermined estimate of the reference frequency, to produce the estimated uplink frequency.

7. The method of claim **6**, wherein step (e) comprises:

subtracting the telemetered successive first count values from each other to produce a first difference value;

subtracting the telemetered successive second count values from each other to produce a second difference value corresponding to the first difference value; and

estimating the BLF based on the first and second difference values and the predetermined reference frequency estimate.

8. The method of claim **7**, wherein:

the first linear combination frequency is equal to $A \cdot f_u + B \cdot f_o$;

the second linear combination frequency is equal to $C \cdot f_u + D \cdot f_o$; and

said estimated BLF ($\hat{f}_u$) is given by $\hat{f}_u = \hat{f}_o (B - Dr)/(Cr - A)$, where

f_u, f_o, and $\hat{f}_o$ respectively denote the BLF, the reference frequency and the predetermined reference frequency, and

r represents a ratio of the first difference value ($\Delta N1$) to the second difference value ($\Delta N2$).

9. The method of claim **1**, wherein the local station is a spacecraft and the remote station is a ground station.

10. In a system including a local station and a remote station, the local station including a receiver, a method of remotely monitoring an uplink frequency of an uplink signal at the local station, comprising:

(a) in the local station, operating the receiver in the locked state when tracking the uplink frequency; concurrently

(b) in the local station, deriving data indicative of a ratio of the uplink frequency and a reference frequency of the receiver;

(c) telemetering the data indicative of the ratio from the local station to the remote station; and

(e) in the remote station, estimating the uplink frequency based on the telemetered data and a predetermined estimate of the reference frequency, to produce an estimated uplink frequency, wherein step (b) comprises:

producing a first linear combination frequency as a first linear combination of the uplink frequency and the reference frequency;

producing a second linear combination frequency as a second linear combination of the uplink frequency and the reference frequency;

repeatedly counting cycles of the first linear combination frequency to produce successive first count values; and

repeatedly counting cycles of the second linear combination frequency to produce successive second count values corresponding to the successive first count values, wherein the successive first and second count values represent the data indicative of the ratio.

11. The method of claim **10**, wherein:

step (c) comprises telemetering the successive first and second count values from the local station to the ground station; and

step (d) comprises estimating the uplink frequency based on (i) the telemetered successive first and second count values, and (ii) the predetermined estimate of the reference frequency, to produce the estimated uplink frequency.

12. The method of claim **11**, wherein step (e) comprises:

subtracting the telemetered successive first count values from each other to produce a first difference value;

subtracting the telemetered successive second count values from each other to produce a second difference value corresponding to the first difference value; and

estimating the uplink frequency based on the first and second difference values and the predetermined reference frequency estimate.

13. The method of claim **12**, wherein:

the first linear combination frequency is equal to $A \cdot f_u + B \cdot f_o$;

the second linear combination frequency is equal to $C \cdot f_u + D \cdot f_o$; and

said estimated uplink frequency ($\hat{f}_u$) is given by $\hat{f}_u = \hat{f}_o (B - Dr)/(Cr - A)$,

where

f_u, f_o, and $\hat{f}_o$ respectively denote the uplink frequency, the reference frequency and the predetermined reference frequency, and

r represents a ratio of the first difference value ($\Delta N1$) to the second difference value ($\Delta N2$).

14. The method of claim **1**, wherein the local station is a spacecraft and the remote station is a ground station.

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